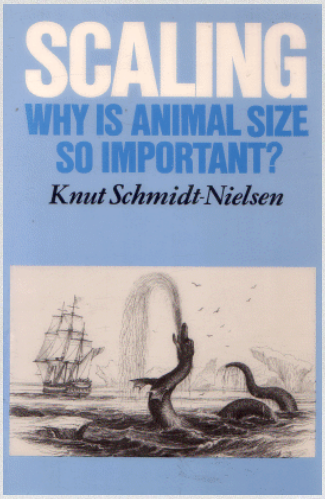
Principles of Size and Shape

- Size and shape have important implications for how animals work in their environment.

Wonders of Life S01E04 Size Matters. Prof Brian Cox.
Watch it from 19:00 to 26:30.



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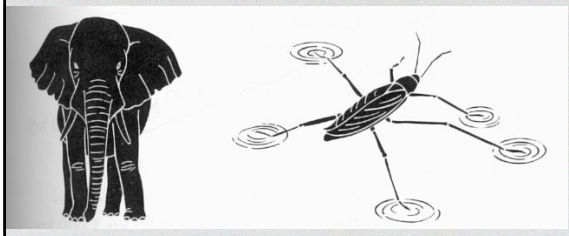
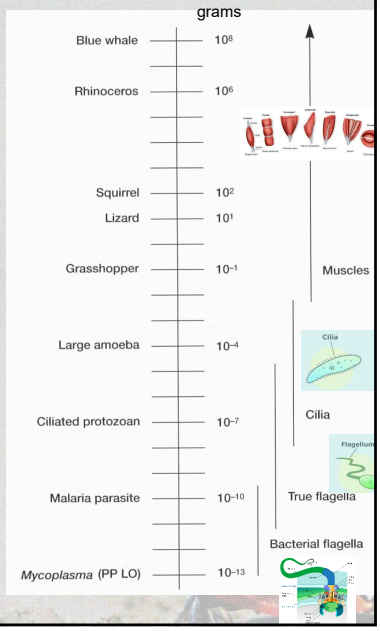
The physical forces that dominate are very different at different scales

- Gravity and inertia dominate for large animals,
- Surface tension and viscosity for small animals



- The type of locomotion is related to size
  - Microbial flagellum
  - Eukaryote flagellum
  - Cilia
  - Muscle



Two videos that illustrate how organisms of different sizes are affected differently by physical forces:
Tl}wmgwsjPmi$lPmi$exPs{$Vi}rspnw$Ryq fiv
Tl}wmgwsjPmi$lXli$Vi}rspnw$Ryq fiv

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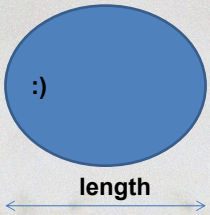
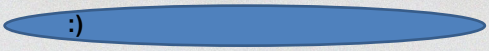
Size

- Two of the most obvious ways to measure size are body length and body mass.
- Which might be more appropriate as a measure of size immediately brings us to a consideration of ……. what is shape?
- It is obvious that two animals of the same body mass can vary considerably in body length; a long thin snake might be much longer than a short, more rotund snake of the same body mass.



length



length

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Size – Mass or Length?

- As we shall see, the physiology of cells is related to the mass of the organism (not length).
- Length is a less relevant measure to physiology than body mass.

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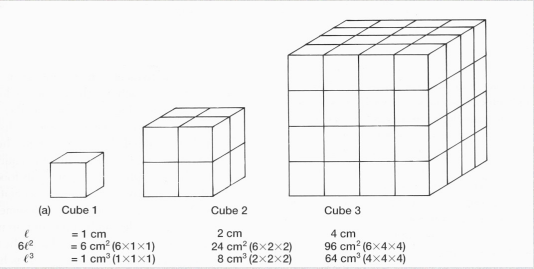
The relationship between mass (M) and length (L)

- Volume is proportional to Length^3 (V α L^3) (Area α L^2)
- Mass is proportional to volume (M α V) (i.e. M α L^3)
- Mass = ρ L^3 (where ρ = density)
  - Mass (grams) is directly proportional to L^3 if L is measured in cm, since ρ is about 1 g cm^{-3}



PS: Weight is mass * gravity (W = m * g); g_{earth}=9.81ms^{-2}

In the absence of gravity, weight can be zero; Mass measure the amount of matter in an object

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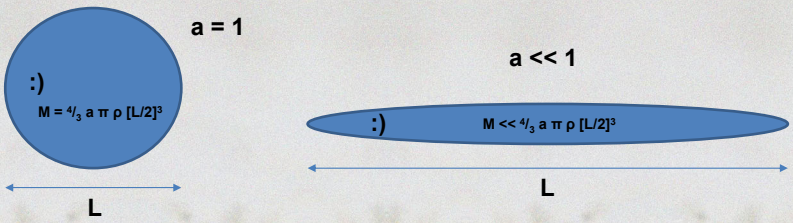
Shape

- Volume and mass is maximal for a spherical animal of given surface area
- For a sphere, M = 4/3 πρr^3 where r=L/2 and L = body length
- The ratio of mass to area is less for elongate animals
  - A proportionality constant "a" is required to equate mass to L i.e. M = a 4/3 πρr^3 .
  - "a" depends on the shape of the animal.



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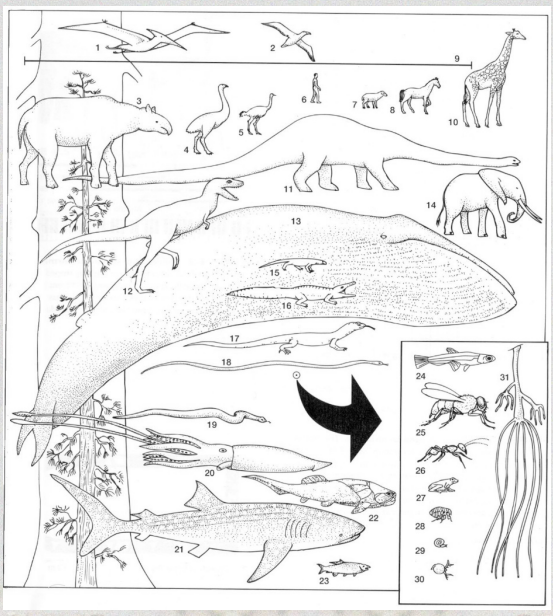
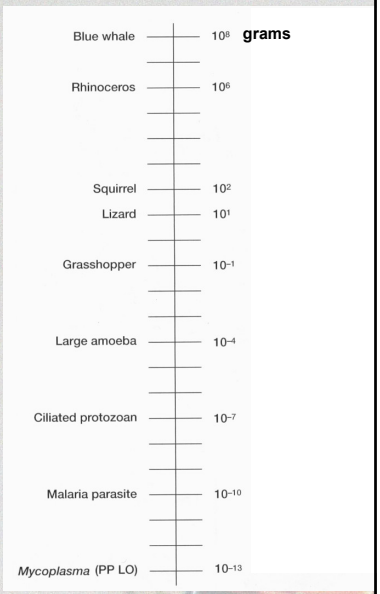
Body mass varies over 21 log units!

Body mass varies immensely, from less than 10-13 grams for a small bacterium to more than 10^8 grams (100 tonnes) for a blue whale





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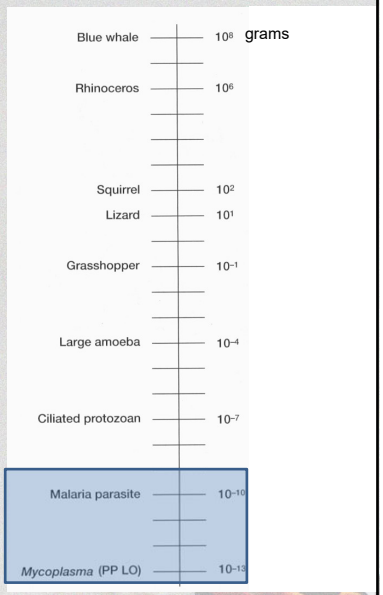
Limits to size

The minimum size of organisms is limited by the molecular scale

The smallest “organisms” are essentially molecular, consisting of a few hundred amino acids (prions) or about 300 nucleotides (viroids).



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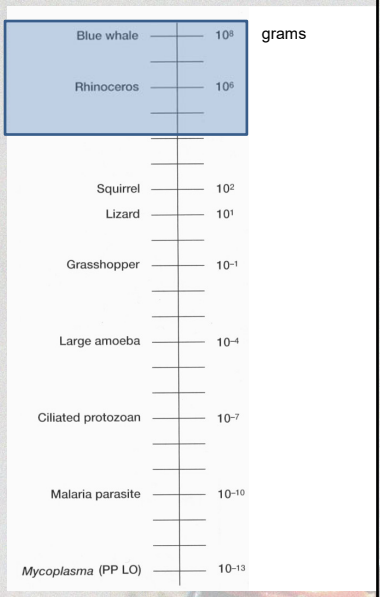
Limits to size

The largest animals are limited by the constraints of being able to resist gravity and distribute nutrients/wastes

- The limit:
  - (about 20 tonnes for terrestrial animals)
  - (about 100 tonnes for aquatic animals).



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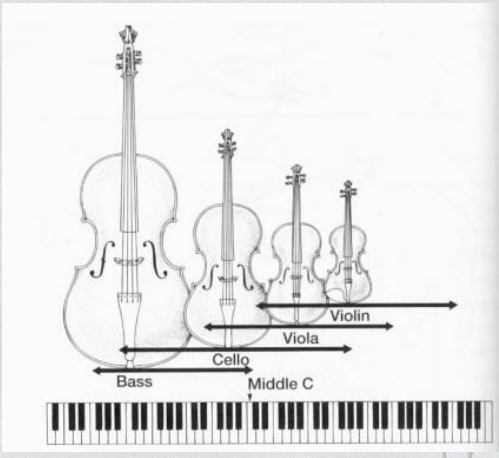
Size affects physiological function

Body mass of organisms has a profound effect on their physiology, as well as their ecology and general life history:

- increase with mass (e.g. tidal volume, basal metabolic rate)
- decrease with mass (e.g. respiratory frequency and heart rate)
- not change (e.g. % body water content)



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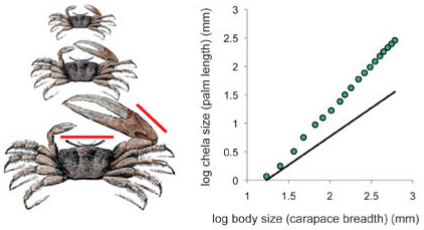
Removing size effects from measurements: Allometry (Scaling)

- Allometry originally was the study of the effect of body mass on physiological variables, but it is now used more broadly to describe how any measure of size (scale), not just body mass, affects structure and function

$$\log y = \alpha \log x + \log b$$



The equation for the linear relationship indicates that its slope (which is the allometric coefficient α) is 1.57. Thus the relationship between chela and body size is **hyperallometric**. The black line illustrates the allometric relationship if it were isometric (slope of 1) (Alexander W. Shingleton © 2010 Nature Education)

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